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A Review of Research Related to Unmanned Aircraft System Visual Observers

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16. Abstract

This paper is a review of human factors research that is related to the task of the visual observer in unmanned aircraft system (UAS) operations. Primarily, visual observers are used to assist in the prevention of a mid-air collision during the course of a UAS operation. Therefore, much of the research reviewed is related to ground-based visual observation of aircraft. The research covers basic human visual system capacity and limitations, visual performance models, and empirical studies of visual observation. The empirical studies include visual observer studies, aircraft see-and-avoid research, and search and rescue operations research.

The results from this research are compared with current visual observer requirements to show where some of the requirements might exceed the capacity of the visual observer to perform adequately. The final section of the document presents recommendations and suggested guidelines for the UAS operations that use visual observers. In addition to their use in avoiding mid-air collisions with aircraft, visual observers can be used to assist the UAS pilot in avoiding difficult to see obstructions such as power lines and guy wires. Observers can also be used to monitor the movements of people and vehicles that might stray too close to an operation. Readers who are not interested in details of the research are encouraged to skip to the guidelines section.

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EXECUTIVE SUMMARY

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INTRODUCTION

One current method for assuring the separation of unmanned aircraft from other aircraft involves, among other restrictions, the use of visual observers that scan for traffic and inform the pilot of an unmanned aircraft (UA) when traffic is in the vicinity of the UA so that its pilot can avoid it. This report will review human factors research related to the human visual system in general and air traffic detection in particular to assist in establishing requirements for visual observers for operations involving unmanned aircraft systems (UASs) in the National Airspace System. One goal of this report is to recommend visual observer procedural requirements that are consistent with known limitations of the human visual system and with limitations of human perception and judgment. In addition, we will recommend training and procedural requirements that will ensure an acceptable level of safety for both the Federal Aviation Administration (FAA) and the public. These recommendations will be based on actual research findings to as great an extent as possible.

Visual Observer Requirements

The establishment of visual observer requirements as they pertain to UAS operations can be traced back to an FAA memorandum, AFS-400 UAS Policy 05-01 entitled, "Unmanned Aircraft Systems Operations in the U.S. National Airspace System – Interim Operational Approval Guidance," which was published in June 2005. In that document, a visual observer was defined as "a trained person who assists the UA pilot in the duties associated with collision avoidance" (Section 5. Definitions).

The most current visual observer requirements can be found in FAA publication N8900.227, "Unmanned Aircraft Systems (UAS) Operational Approval." This publication can be found online at http://www.faa.gov/regulations_policies/orders_notices.

The requirement for the use of visual observers reads: "Unless otherwise specifically authorized, UAS operators must use observers, either airborne or ground-based, to comply with [14 CFR] Part 91 requirements" (from Section 12a). The complete requirements for visual observers within the publication are listed in Section 14a of that publication and is reproduced in Appendix A.

Approach

The approach to the development of this document begins at the general level of human visual system performance and proceeds to specific research relevant to the detection of aircraft. We will review visual observer research that has been conducted both specifically for the detection of unmanned aircraft and visual observer research on the detection of manned aircraft. We will also look at research on the detection of aircraft from other aircraft, search and rescue (air-to-ground) detection, as well as models of visual detection that have been developed. This extensive review of the literature should provide a fairly comprehensive consensus regarding human visual system limitations in general and as it relates to the detection of aircraft in particular. This consensus will then be compared to established visual observer requirements to see if there is a mismatch between those requirements and the expected performance of the observers.

HUMAN VISUAL SYSTEM LIMITS

Information about human visual system limits can be divided into several categories. Foveal vision is the most critical for the identification of objects, but the ability to locate and identify objects is also affected by visual accommodation requirements, peripheral vision ability, and even color vision to some extent. In addition, when performing a task for any length of time, performance on that task is potentially subject to a vigilance decrement. Most of the information in this section was taken from an earlier review of visual system limits (Williams, 2008).

Foveal Vision

Foveal vision provides information to the pilot in the form of symbols and images that can be brought into focus within the visual field of view. It depends on the ability to resolve detail within the visual field of view. This ability is generally referred to as visual acuity. The resolution of detail primarily involves a very small portion of the eye called the fovea, which corresponds to only about 1 degree of the visual field of view (Antuñano, 2002).

The most common answer to the question of visual system limits uses the angular size of an object in relation to the total visual angle impinging on the eye at any given moment. When expressed in terms of angular size, the most commonly accepted resolving ability of humans is 1 min of visual arc ($1/60^{th}$ of a degree) (O'Hare & Roscoe, 1990). For example, an object that has a visual cross-section of 1 ft and is 3,438 ft from an observer subtends 1 min of visual arc, so an object that has a 1 ft visual cross-section can theoretically be recognized from as far away as 3,438 ft.

Of course, visual acuity can be degraded relative to this theoretical limit by several factors. For example, low light levels and low contrast between an object and its background both affect object visibility. Visual acuity can also be affected by physiological factors. Alcohol and tobacco use, low blood sugar, and sleep deprivation can impair vision. In addition, inflight exposure to low barometric pressure without the use of supplemental oxygen (above 10,000 ft during the day and above 5,000 ft at night) can result in hypoxia (low blood oxygen levels), which can also impair vision (Antuñano, 2002).

For these and other reasons, the National Transportation Safety Board (NTSB) has stated that an aircraft must subtend at least 12 min of visual arc before there is a reasonable chance of it being seen (NTSB, 1987). Furthermore, a report by the Australian Bureau of Air Safety Investigation states that in sub-optimal visual conditions, a figure of 24 to 36 min of arc is more realistic (Hobbs, 1991). Using the NTSB value of 12 min of visual arc, an object that spans 1 ft of visual width could be seen only if it were as close as 286 ft. In sub-optimal conditions (requiring 36 min of visual arc), this same object would only be seen if it were within 95 ft of the viewer.

In addition to environmental and physical factors, visual acuity drops rapidly as an object falls outside of the 1-degree area of foveal vision. Harris (1973), for instance, demonstrated that the probability of detecting a DC-3 aircraft at a range of 5 mi was 100% when looked at directly, but the probability dropped to less than 20% when the image was displaced as little as 10 degrees from the center. Among other things, this finding demonstrates the criticality of visual scanning procedures that systematically vary the direction of gaze.

Visual Accommodation

The ability to shift the focus of the eye to various distances is called accommodation. Accommodation is affected by age and fatigue, as well as other factors. Hobbs (1991) suggests that the average pilot probably takes several seconds to accommodate to a distant object. In addition, visual accommodation can be affected by objects that are interposed between the viewer and the object to be seen. It can also be affected by a lack of objects so that staring into a clear sky can cause the eyes to focus only a short distance from the viewer (empty-field myopia).

Peripheral Vision

While the majority of visual information is processed within the central 1-degree vertical and horizontal visual field, the entire visual field of the eyes is normally about 190 degrees on the horizontal plane and 120 degrees on the vertical plane (Diffrient, Tilley, & Harman, 1981). The non-central field of view is referred to as peripheral vision. The peripheral field of view can be separated into a portion that is still somewhat sensitive to colors, and a wider portion that is not. The color-sensitive field is sometimes referred to as parafoveal vision. Estimates vary, but parafoveal vision includes approximately the central 10-degree visual field (Gilbert, 1950).

Most of the information that is conveyed through peripheral vision is about movement. This includes both movement of objects within the field of view and movement of the individual through space. This information is not very precise but serves more to attract the attention of the viewer to a location.

Vigilance

When conducting a task such as scanning for traffic for any length of time, there is the possibility that fatigue or boredom could affect the ability of the observer to perform the task adequately. Laboratory studies of potential vigilance decrements for visual scanning tasks have shown that a performance decrement will usually occur between 30 minutes and an hour into the task (Boff & Lincoln, 1988). However, a large number of variables can affect the performance of vigilance tasks, including event rate (i.e., how often a stimulus appears); discrimination task difficulty; sensory modality, or combinations of sensory modalities; source complexity; signal duration; signal intensity; multiple signal sources; discrete versus continuous events; intermittent versus continuous attention requirement; observer skill level; and task value (Parasuraman & Davies, 1977).

While there could be much more said in regard to the limitations of the human visual system, the primary point to be made is that human vision is often unreliable, even under the most ideal conditions. Unfortunately, the most ideal conditions are rarely available, and most of the research concerning the ability of humans to locate aircraft demonstrates that being theoretically able to see an aircraft does not ensure that it will be seen.

VISUAL MODELING RESEARCH

Many attempts have been made to create a mathematical model of the human ability to visually detect aircraft. Because of the complexity of the problem, no single model addresses all relevant factors, although more recent models successfully address more factors simultaneously and provide a point of analysis prior to designing real-world tests. As discussed earlier, the real world presents a number of non-trivial factors that will influence visibility and detectability but cannot be easily included in a visual model. These factors include contrast between the target and the background, navigation and other artificial lights in day and night environments, size, orientation, visual clutter, and the location of the image on the retina (Andrews, 1991; Williams, 2008; Watson, Ramirez, & Salud, 2009).

Table 1 lists a few examples of the visual-modeling research that has been conducted, along with a description of that research and some of the major findings.

Table 1. A comparison of several visual models and modeling research studies.

Visual Model or Research	*Description*	*Take-Away Finding*	*Author/s*	*Year*
Spatial Standard Observer (SSO)	Computes contrast thresholds for arbitrary grayscale images	"It is not possible to know the visible range of an aircraft without knowing its size, shape, orientation, brightness, and the brightness of the background sky."	Watson, Ramirez, & Salud	2009
Howell (1957) Experimental Findings	Empirical study on DC-3 detection	When apprised of the direction of approach, an observer was able to detect a DC-3 at a range of 17.3 to 23 km. When consigned to an uninformed search task the detection ranges shrank to 5.5 to 8.7 km.	Howell	1957
Harris (1973) Experimental Findings	Model-based analyses of the detection ranges of DC-3, DC-8, and 747 targets presented at 0, 45, and 90-degree angles from a head-on approach	Using such constraints with no atmospheric attenuation the DC-3 target at a 45 degree orientation was theoretically visible from 18 km.	Harris	1973
DoD OPEVAL Group: Visual Detection in Air Interception, A Comparison of Theory with Trial Results	Data collected on F7F, F8F, and TO-1 (P/F-80C) Shooting Star "target" aircraft air-to-air detection (PAX River 1948-1949) compared to model predictions	The max detection range when the target is at a 120 degree aspect angle varies from approximately 14NM for the TO-1 (bare aluminum) to 20NM for the F8F.	DoD OPEVAL Group	1952 US Navy (1952)
Office of Chief of Naval Operations: Probability of Visual Detection in Air Interception	Computes probability of detection based on: • contrast • meteorological visibility • max range without haze • size of target • aspect angle of target • elevation scanning angle • azimuth scanning angle • presented area of target • relative velocity • range search is begun • max range detection possible under given conditions (limits of vision when gazing directly at target)	Theoretically, the specified method can be used to compute probability of detection for any UAS/SUAS or manned A/C. However, no empirical data is presented.	CNO	1951 released 1972 US Navy (1949, 1951)
Model of Operator Performance in Air Defense Systems (MOPADS)	Computes the probability of an observer detecting a target based on 8 variables: 1) target type 2) horizontal range to target 3) apparent contrast 4) search area 5) target altitude 6) days on station 7) use of binoculars and 8) target path offset	Many of the variables were incorporated into the model based on findings from forward visual observer research (discussed in this report).	Gawron, Laughery, Jorgensen, & Polito	1983

As an example visual model, we will take a closer look at the Spatial Standard Observer (SSO) model of Watson, Ramirez, and Salud (2009). The SSO provides the capability to estimate the minimum contrast threshold and the maximum distance threshold. The estimations initially made with the model assumed no atmospheric attenuation. The model's predictions were compared to three human observers and to the results of a live flight experiment using a Douglas DC-3 aircraft as the stimulus (Howell, 1957). The predictions made by the model compared favorably to human performance. At maximum contrast, Cessna 172 and MQ-9 sized aircraft are only visible when within 10 km (6 miles) or less. The model predicts that in non-attenuating conditions a 90% reduction in contrast lowers the detection range to less than 5 km (3 miles). Different environmental conditions and changes in aircraft color can be expected to significantly reduce these distances. Changes in size or distance from the aircraft resulted in the largest changes to the observer's detection threshold when compared to changes in aircraft orientation or contrast from the background (Watson, Ramirez, & Salud, 2009). For a visual observer, this means the probability of detection increases most by reducing the distance to the aircraft more than by changes in contrast or aircraft orientation. In other words, distance is more important than atmospheric conditions for aircraft detectability.

In both the Howell (1957) and Watson, Ramirez, and Salud (2009) studies, the participants knew where to look for the stimuli and thus were relieved of the burden of a search task. The requirement to search for the stimulus can greatly reduce detection distance.

Models can provide a range of distances from which one can expect to detect an aircraft under any given set of circumstances. The challenge arises when a human observer is tasked with detecting aircraft in the dynamic, visually complex operational environment. Given the safety-critical nature of see-and-avoid, optimal and average detection ranges should be treated as a limited probability, rather than a capability. The pessimistic assumptions will be experienced in the operational environment often enough to warrant using these metrics as a basis for requirements. Furthermore, the limitations of the visual system cannot be the only limiting factors taken into account. For example, the difficulties of maintaining a vigilant scan (Boff & Lincoln, 1988) create additional hindrances to detecting approaching aircraft.

While the use of visual models might be useful when planning some operations, as previously mentioned, many variables are not accounted for in any of the models that will affect the probability of visual detection. In addition, some of the variables, such as contrast ratio, can change during an operation due to changes in atmospheric conditions, position of the sun, or other factors. Therefore, the use of visual models is not recommended as a means of establishing exact visual distance requirements for visual observer operations.

VISUAL OBSERVER RESEARCH

Although the literature indicates only two experiments related to UAS visual observer performance (Crognale, 2009; Dolgov, Marshall, Davis, Wierzbanowski, & Hudson, 2012), there are several decades worth of research regarding the ground-based observation of aircraft (e.g., Kurke & McCain, 1957; Wokoun, 1960; Zimmer & McGinnis, 1963; Wright, 1966; Frederickson, Follettie, & Baldwin, 1967; Baldwin, 1973). Baldwin (1973) provides a summary of most of this research, which focused on the use of so-called "forward observers" used for the detection and recognition of enemy aircraft within a protected military zone.

Forward Observer Research

Although the experiments summarized by Baldwin (1973) looked at several issues, of most relevance to the current paper are the studies that focused on the detection of aircraft from the ground (Kurke & McCain, 1957; Wokoun, 1960; Zimmer & McGinnis, 1963; Wright, 1966; Frederickson, Follettie, & Baldwin, 1967). In summarizing this research, Baldwin makes the following conclusions:

- Limiting the extent of the search sector had a strong effect on the distance at which aircraft detection occurred. Thus, detection distances averaged 1.25 miles (2,000 meters) when search sectors were large (i.e., 180 to 360 degrees), and no information was provided regarding the expected time of approach of the intruder aircraft. However, detection distances averaged 7.5 miles (12,000 meters) when the search sector was narrowed to 5 degrees, and the observer was provided information regarding when the aircraft would enter the area.
- The use of hand-held binoculars did not assist in detection and, when terrain features blocked the view of the horizon, could lead to worse detection than unaided visual search.
- Aircraft approaching at 500 ft (152 meters) above ground level (AGL) were detected more quickly than aircraft approaching at 1,500 ft (457 meters) AGL.
- Aircraft were detected earlier when the observer was offset from the path of flight.
- Attempts to teach specific search pattern techniques yielded equivocal results, with training assisting some observers but hampering others.

All of the studies reviewed by Baldwin (1973) were conducted during the daytime, mostly in flat desert terrain with very few structures in the area but some mountains in the background. These conditions would provide a very good visual environment for detecting aircraft unless the approach was performed in front of the mountainous terrain. None of the studies looked at nighttime or dusk/dawn conditions. Despite these restrictions, the research provides useful information on the use of ground observers to detect aircraft visually.

Crognale (2009)

One of only two studies of visual observer capabilities is reported by Crognale (2009). Crognale conducted a series of four experiments looking at the effectiveness and capabilities of visual observers. The first experiment tested the ability of 15 observers to detect an unmanned aircraft approaching head-on from an unknown direction. The system used for the first experiment was a Scan Eagle UAS, a relatively small (approx. 40 lbs) aircraft with a wingspan of 10 ft. Two different Scan Eagle aircraft were flown. One was painted gray and the other was orange (note, though, that no significant differences were found due to color of the aircraft). The observers wore earplugs to prevent the sound of the UA from acting as a cue to its position. Observers were told to look down at the ground until the UAS pilot had positioned the aircraft at one of eight direction points from the observer (N, NE, E, SE, S, SW, W, NW) approximately 1.5 kilometers (0.93 miles) in distance and had begun to approach the observer position. They were then told to begin scanning for the UA and to report when they saw it.

Of 240 flight trials, observers detected the aircraft 224 times, for a detection rate of approximately 97%. However, successful detection of the aircraft does not ensure that there is enough time to alert a pilot and for the pilot to perform a collision avoidance maneuver. The mean detection distance across all subjects was 327 meters (approximately 1,073 feet) with a range of 21 to 1,400 meters. A detection distance of 327 meters would provide approximately 13 seconds to formulate and perform a collision avoidance maneuver at normal cruise speeds for these aircraft. Edmunson (2012) suggests that at least 12 seconds are required for a pilot to determine the need for, and perform a collision avoidance maneuver. If we define a successful detection only as one that provided at least 12 seconds of response time (i.e., 300 meters or greater), the rate of successful detections drops to 118 out of 240, or approximately 49%.

The mean detection distance can be compared to that predicted by the Spatial Standard Observer visual modeling program discussed in the previous section. The SSO model predicts a visual detection distance of .8 km (800 meters) to 1.5 km (1,500 meters), depending on the contrast ratio of the target to its background. Clearly, actual performance of the visual observers was notably less than that predicted by the SSO. Crognale (2009) attributed most of this difference to scanning inefficiencies by the observers, as well as the large degree of uncertainty associated with the location of the target. These inefficiencies were present across all observers, regardless of age, experience with visual observation, or gender.

The second experiment tested the ability of visual observers to judge the distance and altitude of an unmanned aircraft. Fourteen participants were tested two or three at a time. Participants followed the flight of a Scan Eagle as it flew around the test range. At 10 designated points on the range, the UA would orbit, and the participants would estimate the distance and altitude of the aircraft. The orbit points represented all combinations of distances of .25, .5, and .75 miles and altitudes of 500, 1,000, and 1,500 feet, plus the repeated combination of .5 miles distance and 1,000 feet in altitude.

Results showed that participants were relatively poor at judging both distance and altitude of the UA. Average error in distance estimates was approximately 40% greater than the actual distance. Altitude errors were even worse, averaging approximately 60% from the actual altitude. As with distance, there was a tendency to overestimate the actual value, particularly at lower altitudes.

The third experiment was intended to evaluate detection distances under conditions of reduced uncertainty regarding the position of the UA. In this experiment, participants followed the flight of the UA as it flew directly away from them, noting when they could no longer detect the aircraft. The experimenters would then reverse the course of the UA and participants would indicate when they could again detect the aircraft. Results showed that the average detection limit of the aircraft as it flew away from the participants was 1,276 meters (4,186 ft). Average detection distance to reacquire the aircraft was 898 meters (2,946 ft). Both values are substantially greater than the value found in Experiment 1 (327 meters) and are fairly close to those predicted by the SSO visual modeling program. We assume that the increase in detection distance here is due primarily to the decrease in the search area.

The final experiment by Crognale (2009) tested the ability of visual observers to estimate the potential for a collision between a UA and another aircraft. Although the experimenters had difficulty with the experimental protocol, one interesting result from this last experiment was the finding that the visual observers were unable to estimate the potential for a collision if they could not see both aircraft at the same time.

Dolgov et al. (2012)

One final study of UAS observers was conducted by Dolgov et al. (2012). This research focused on a comparison of day, dusk, and night conditions for their effect on visual observer capabilities. In addition, data were collected regarding the ability of an observer to judge whether an intruder aircraft was on a collision course with the UAS. The major conclusions of the research were:

- There was no degradation in safety between day and night conditions, and measures of visibility analyzed in the study favored the night conditions.
- Manned aircraft involved with the study, but not the small UAS used, were acquired further away at night than during the day.
- Performance in judging the potential for a collision varied dramatically among the observers used in the study but, in general, was poor. There was some indication that an observer that was co-located with the pilot would be more successful than one that was offset. However, methodological problems do not allow this conclusion to be made with confidence.

One body of research that is similar to ground-based visual observer research is aircraft see-and-avoid research. The following section will cover this research.

AIRCRAFT SEE-AND-AVOID RESEARCH

Research on the ability of a pilot to see and avoid other aircraft has been conducted for over 50 years (e.g., Howell, 1957; Zeller, 1959). The majority of this research has found a consistent inability on the part of a pilot to see other aircraft with a high degree of probability (e.g., Hobbs, 1991). Limitations of see and avoid have been shown in both actual flight tests (Andrews, 1977, 1984, 1991) and simulation studies (Wickens, Helleberg, Kroft, Talleur, & Xu, 2001; Colvin, Dodhia, & Dismukes, 2005; Morris, 2005). Morris (2005) reports that a failure to see and avoid the other aircraft was noted as a primary factor in 94% of all mid-air collisions that occurred in the U.S. from 1991 to 2000. In the studies by Andrews, both alerted and unalerted visual detection were measured. The probability of successful visual detection when no alert was issued was approximately 56% (Andrews, 1991). Alerted visual detection increased the probability of detection, as might be expected (Andrews, 1977, 1984), but a cumulative probability of detection did not exceed 80% in sufficient time to allow a successful pilot response.

Factors Affecting See and Avoid

From the literature on aircraft see-and-avoid research, we find many factors that contribute to problems with accomplishing see-and-avoid tasks successfully (Hobbs, 1991; Morris, 2005; Edmunson, 2012). Many of these factors are present with visual observers. However, some of them do not apply directly to visual-observer activities. We will describe several of these factors below and discuss how they do or do not apply to the visual observer.

Small Visual Angle

The visual angle that is subtended by an approaching object does not increase linearly with the distance of the object. In fact, for most of the time in which an approaching object can be seen theoretically, the visual angle is relatively small. The faster the closing speed of the object, the less time there will be available for the object to become large enough to be seen with any degree of certainty. In support of this assertion, Edmunson (2012) reports that direct measures of see-and-avoid performance show that as the closing speed of two aircraft increases from 100 kts to 400 kts, the probability of detection decreases from approximately 84% to 32%. Because the amount of time available to detect an approaching object is determined by the relative closing speed, a stationary visual observer would have a decided advantage over the pilot of a manned aircraft on a head-on collision course.

Cockpit Obstructions

Scanning for aircraft from inside a cockpit can be hindered by aircraft components, passengers, the propeller disk, glare on the windscreen, and windscreen imperfections (Morris, 2005). In addition to potentially obscuring air traffic, such objects can become focal traps, causing the eyes to focus at a closer distance than is needed to spot other traffic. While ground-based visual observers would not be affected by cockpit obstructions, there might still be objects in the vicinity (e.g., power lines, buildings, billboards) that could serve as obscurations and focal traps to the observer.

Visual Acuity

As mentioned earlier, visual acuity drops rapidly outside of a 1-degree center of the eye's visual field. Scan patterns are vital to ensuring that an area is clear of traffic. There are also other factors that can further affect the ability to focus, including age, fatigue, light/dark adaptation, and hypoxia. All of these factors, with the possible exception of hypoxia, can be expected with ground-based visual observers.

Visual Accommodation

Visual accommodation refers to the act of focusing on an object. When gazing into an empty space, such as a clear blue sky, the eyes tend to focus within a few feet of the individual (Roscoe & Hull, 1982). This phenomenon, known as empty field myopia, makes it more difficult to detect objects further away. Also, as was mentioned earlier, obstructions to the line-of-sight can cause the eyes to focus at those distances. Pilots and visual observers would both be vulnerable to problems with visual accommodation.

Poor Contrast

Contrast refers to the difference in luminance between an object and its background. The larger the difference in luminance, the better is the contrast. Factors that can affect contrast are paint schemes, aircraft lighting systems, atmospheric conditions, and variations in background. Night operations have a potential advantage of higher contrast conditions (between the dark sky and aircraft lights). However, operations conducted against a background of lighted objects (e.g., city lights) could reduce the effectiveness associated with high contrast levels and serve to camouflage potential targets.

Complex Backgrounds

When the background behind an object contains a variety of luminance levels and contours it becomes difficult to visually distinguish the object from its background (Hobbs, 1991). This situation would be made even more difficult if the object itself contained a variety of luminance levels and contours. It is likely that this complex background effect would be seen more often between air-to-air observations than between ground-to-air observations. However, the presence of tall buildings or terrain could be problematic in both cases. In addition, Hobbs cites literature that concludes that the potential for complex backgrounds, while it can occur in both foveal and peripheral vision, is a more serious problem in peripheral vision. This suggests that scanning is a more critical issue for operations that occur where the potential for interference from complex backgrounds is greater.

Lack of Apparent Motion

The human visual system is much better able to locate and attend to an object moving across the field of view than one that remains at a fixed position within the field of view (Hobbs, 1991). For the pilot of a manned aircraft this is a problem because traffic that is on a collision course with one's own aircraft

remains in a fixed position within the field of view. On the other hand, visual observers are watching for traffic that might be on a collision course with a UA, but this traffic would not be on a collision course with the visual observer. Therefore, relevant traffic will still be moving across the field of view of the observer.

Visual Search Requirements

Research has shown that pilots scan for traffic only around 30-35% of the time on average (Wickens et al., 2001). This percentage can be negatively affected by workload demands within the cockpit or distractions outside of the cockpit that might attract the pilot's attention. Further, scanning patterns can be both inconsistent and incomplete, such that large portions of the visual field are neglected (Colvin et al., 2005). Morris (2005) performed a visual-scanning modeling analysis, concluding that the probability of detecting a converging 40-ft wide target for a pilot scanning for traffic 33% of the time varied from .723 when the closure speed was 100 kts to .162 when the closure speed was 300 kts.

Of course, restricting the area that is scanned should increase the probability of detection, assuming that the target is actually in the restricted area. Morris (2005) assumed a visual field of 270 degrees for his analysis. Howell (1957) demonstrated that, when apprised of the direction of approach, an observer was able to detect a DC-3 at a range of 17.3 to 23 km. When consigned to an uninformed search task, the detection ranges shrank to 5.5 to 8.7 km (Howell, 1957). In addition, the research cited earlier regarding forward visual observers showed that visual detection ranges increased as the visual field decreased (Baldwin, 1973).

In regard to visual search requirements, visual observers have some advantages over the manned aircraft pilot. First, visual observers do not have other activities to perform while conducting a visual search and can therefore spend close to 100% of their time looking for traffic. Second, the use of multiple visual observers can allow the field of view to be smaller for each of the observers.

Comparing Pilot See-and-Avoid to Visual Observation

While there are many factors that affect both the pilot of a manned aircraft and a visual observer, the visual observer has a decided advantage in a few areas. The ability of a visual observer to devote up to 100% of his or her time scanning for traffic affords a much greater probability of detecting traffic relative to the pilot of a manned aircraft that typically spends only 35% of the time at this task. In addition, conflicting traffic are more likely to be in relative motion to the ground observer than to the pilot of a manned aircraft and thus more likely to draw the attention of the observer. Visual observers are less likely to have objects obscuring their view of the traffic, but this could be offset by the empty field myopia effect that would occur while looking up from the ground into a clear sky. Finally, the use of multiple observers can allow each observer to restrict the field of view that is required to be scanned, thereby increasing the likelihood that a complete scan occurs when traffic is within the field of view.

In addition to these advantages, the visual observer also has the potential advantage of being able to hear an approaching aircraft, assuming the ambient noise level is relatively low. Also, the visual observer, unlike the pilot of most general aviation manned aircraft, can be rotated out for rest to prevent vigilance decrements in the task.

OTHER RELEVANT RESEARCH

Air-to-Ground Search

An activity that has many similarities to visual observer duties is air-to-ground search, such as occurs during search and rescue (SAR) attempts. A study by Canadian researchers Croft, Pittman, and Scialfa (2007) looked at the performance of search and rescue spotters and attempted to identify factors that contributed to successful performance. The research was attempting to confirm earlier laboratory studies by Stager and Angus (1975, 1978) using a real-world SAR environment.

Croft et al. (2007) found a search success rate of 30%, which was better than the success rate reported by Stager and Angus of 12%. An analysis of factors that predicted successful performance suggested that spotters were more successful when there was a tendency for a large number of gaze fixations that were spaced relatively close together. In addition, hit rates were higher when both central and peripheral visual function was good. These results suggest that training might affect the success rate, but there are also innate factors that will influence the success rate as well.

One factor influencing the success rate for SAR spotters is that they are in a moving aircraft and have a limited amount of time to scan any particular location. Measurements by Croft et al. showed that spotters only looked at between 17% and 31% of a particular region before the aircraft had completed movement through the region. Visual observers have the advantage of being stationary. However, unlike SAR operations, the target is moving. If the area they are observing is large, a thorough scan of the region can take a long time to complete and increases the likelihood that an intruding aircraft will move through the area at a time when the scan pattern is at a different location.

Laser Operations Observers

Another activity that has similarities to visual observer requirements is that of a laser operation safety observer. The task of a laser safety observer is to "observe the airspace through which a laser beam is being propagated to ensure that the beam does not illuminate any individual or object that could be injured, impaired, or damaged as a result of such an exposure" (SAE, 2003, p.7). This SAE (Society of Automotive Engineers) document does not review any research related to the ability of visual observers to detect aircraft. However, it does provide useful recommendations regarding the minimum criteria for visual observers to perform their task effectively. These recommendations include the physical capabilities of the observers, including visual and auditory abilities, and limitations on the use of medications and alcohol. The document also includes training recommendations regarding visual scanning patterns, communication protocols,

use of different types of eyeglasses or contact lenses, effects of various environmental factors on visual detection, potential types of visual illusions, and fatigue awareness and recognition. Finally, the document provides recommendations regarding operating procedures (including not performing any other duties), the length of time on duty, the use of rest breaks, and dark adaptation requirements. Regarding dark adaptation requirements, the document recommends at least 30 minutes for an observer to be fully adapted to the dark and that exposure to bright lights or the use of tobacco products can delay adaptation. The reader is directed to SAE (2003) for full information regarding these recommendations.

DISCUSSION

The use of visual observers for the prevention of mid-air collisions between an unmanned aircraft and a manned aircraft is a natural extension of see-and-avoid operations in manned aircraft. However, instead of the pilot of an unmanned aircraft performing the "seeing" function, that task is delegated to a third person. This requires an extra step in the process where the visual observer must communicate the presence and position of the intruding aircraft to the pilot. If the UA pilot is unable to locate the intruding aircraft, the visual observer must also determine if a collision is likely and provide enough information regarding the direction of flight of the intruding aircraft so that the pilot can maneuver the UA to prevent a collision.

In a sense, this approach is analogous to having an observer in a manned aircraft that is watching for traffic while the pilot performs other flight duties. However, in the case of a UAS operation, the visual observer is not necessarily co-located with the pilot and therefore would have more difficulty communicating to the pilot the location of the intruding aircraft. Instead of simply pointing at the aircraft, the observer would have to provide direction and altitude information that would be useful enough for the pilot to successfully locate the aircraft or, alternatively, provide maneuvering information that would successfully prevent a collision.

The research that we have reviewed in this paper, for the most part, suggests that the ability of a human, either pilot or observer, to see aircraft is problematic even under ideal visual conditions. Furthermore, this ability is negatively influenced by a number of environmental and physiological factors. Additionally, even if an intruder aircraft is located, the ability of an observer to determine whether the aircraft is on a potential collision course with the unmanned aircraft is also difficult (Crognale, 2009; Dolgov et al., 2012). It is not clear whether extensive training would improve this ability or not.

Given these research findings, it could be argued that the use of visual observers is not very effective. However, we believe that there are many potential UAS operations where the implementation of electronic sense-and-avoid systems is not feasible or cost-effective. For these operations, the use of visual observers is still the best way to provide an extra level of safety in regard to separation from other air traffic. In addition, visual observers can be used to assist the UAS pilot in avoiding other obstacles, such as power lines, towers, and guy wires. They can also be used to monitor crowds to inform the pilot whether the UAS might impose a potential hazard to anyone on the ground.

What is needed, however, is a clarification of the duties of the visual observer so that the expectations of their abilities are not exceeded by the requirements of the operation. That is, the agency cannot require more from visual observers than what is reasonably expected of them to be able to accomplish. The following paragraphs list requirements that have been imposed on visual observers in previous operations and/or current guidelines that have most likely exceeded actual observer abilities.

Maintaining Visual Contact With Small UAS

Specifying an exact distance of how far an unmanned aircraft can be from an observer or pilot and still be seen is difficult at best. Visual models can probably provide a range of values, but a number of factors are simply not knowable. These would include the scanning efficiency of the observer, observer level of vigilance, the potential for a complex background to obscure the target at a precise point in time, and others.

Maintaining Visual Contact With a UAS While Scanning for Traffic

One problem with the use of a visual observer as an extension of the pilot is the notion that the observer must remain aware of the position of the unmanned aircraft at all times while scanning for other traffic. This notion is not supported either with empirical research (Crognale, 2009; Dolgov et al., 2012) or with what we know about human visual abilities and processes (Antuñano, 2002). Because precise visual acuity is restricted to only about 1 degree of the field of view, it is extremely unlikely that an observer can maintain observation of an unmanned aircraft and still be able to look for other aircraft in the vicinity. In addition to the disruption of scanning patterns, this requirement would also force observers to re-accommodate visually, which can take several seconds to accomplish (Hobbs, 1991). These tasks must be separated. If a visual observer is required for a particular operation to maintain visual contact with the UAS (e.g., to assist in the avoidance of wires or other obstacles), they should not be expected to watch for traffic as well.

Judging Collision Potential of an Intruding Aircraft

The ability to judge collision potential, according to the research by Crognale (2009), is limited by whether the observer can maintain both the UAS and the intruding aircraft within his or her field of view. Given the difficulty of simultaneously looking for traffic and maintaining visual contact with a UAS, trying to accomplish both tasks would render them both ineffective.

Informing the Pilot-in-Command (PIC) of Impending Loss of Visual Contact

Section 14a(1)(c) of FAA publication N8900.227, "Unmanned Aircraft Systems (UAS) Operational Approval," states that visual observers "must inform the PIC before losing sufficient visual contact with the UA or previously sighted collision hazard." This requirement assumes that a visual observer will be aware that they are about to lose visual contact with either the unmanned aircraft or an intruder aircraft. This assumption is problematic because of the possibility that any momentary distraction of the observer would disrupt visual contact. As shown by Crognale (2009), continuous visual observation of an aircraft moving away from you allows visual contact to a much greater distance than acquiring an object moving toward you. In other words, even if an object can be seen clearly by an observer, the object cannot necessarily be reacquired if visual contact is momentarily lost. Because of this fact, the observer will not be aware of the distance at which visual contact might be lost, so informing the PIC that they are about to lose visual contact is unlikely to occur.

CONCLUSIONS

The requirements for the use of visual observers in many UAS operations will likely remain for many years, even after the development of detect-and-avoid technology. This will be especially true for small UAS that will not be able to accommodate onboard detect-and-avoid systems because of weight and size limitations or because of the ad hoc nature of many small UAS operations that must remain clear of obstacles and avoid endangering bystanders on the ground. The following section lists guidelines for the selection, training, and use of visual observers, based on the research findings presented in this report and the known human factors limitations of both visual observers and UAS pilots.

GUIDELINES FOR THE USE OF VISUAL OBSERVERS

Role of the Visual Observer

Although a primary responsibility of the visual observer is to scan for traffic, there are other potential uses for visual observers, even in operations where conflicting traffic is not anticipated. Visual observers can be used to assist the UAS pilot in avoiding hard-to-detect obstacles such as power lines, guy wires, or antennas. They can also be used to monitor ground traffic, both people and vehicles, so that the UAS pilot can maneuver away from them to protect them in the event of an unexpected failure of the aircraft. The need for any or all of these functions will be dependent on the particular operation.

Protected Area of Operations

For all types of operations, there will be a defined area to which the UA will be restricted. If it remains within this area, a primary task of the visual observer is to detect aircraft that might potentially enter the area, thus protecting the entire area from other aircraft. This idea of a protected area of operations (PAO) makes the visual observer's task easier to perform because the observer does not have to estimate whether an intruding aircraft is on a collision course with the UA but only with the PAO.

The extent of the PAO is determined by a number of factors. The first factor, type of datalink, will be one of two types. The first type involves a UA that is tracked only by direct visual contact. The position of the aircraft is not transmitted electronically, and all information regarding position, altitude, and attitude is obtained visually from the ground. The second type of datalink operation involves a UAS that transmits its position, altitude and attitude information to a receiving device on the ground.

It is imperative that a UA that is tracked visually remain in sight of the UA pilot. This will limit the PAO for that aircraft to the visual range of the pilot. For smaller systems, this is probably no more than ¼ mile, depending on atmospheric and lighting conditions. On the other hand, a UA that transmits its location can be tracked using a moving-map display system. Its location is known even if it moves beyond visual sight of the pilot. This would allow for a larger PAO, as long as steps are taken to prevent collisions with other aircraft or obstacles, probably with the use of visual observers.

Operational Altitudes

The height of the PAO is critical in determining the potential to encounter manned aircraft during an operation. Title 14 of the Code of Federal Regulations (CFR) part 91.119 restricts manned aircraft from operating below at least 1,000 feet over congested areas of cities, towns, settlements, or open air assemblies of people. It restricts aircraft from operating below 500 feet over uncongested areas, except for open water and sparsely populated areas (full text of 14 CFR 91.119 is reproduced in Appendix D). Some UAS operations can be restricted to altitudes beneath those specified in §91.119. If the operation is beneath the specified altitudes, there should be much less risk of colliding with manned aircraft.

- If the PAO lies within an altitude determined by §91.119 to be free of traffic, no observer is required for traffic avoidance. However, there still might be a requirement for an observer for the avoidance of obstacles, monitoring crowd movements, or monitoring other unmanned aircraft operating within the PAO.
- If the PAO extends to an altitude that is not prohibited by §91.119, the number of visual observers is determined by the physical extent of the PAO. In general, more is better. However, the goal is to position enough observers so that aircraft approaching the PAO can be seen before they reach it.

Pre-Operational Activities

There are several aspects about the area of operations in which the UA will fly that should be known in advance of the operation. These include:

- Weather conditions—wind, visibility, and the likelihood of severe weather;
- maximum obstruction height within the PAO;

- position of guy wires, power lines, or other difficult-to-see obstructions;
- presence of crowds or vehicles that might interfere with the operation;
- potential signal interference sources;
- local air traffic patterns; the position and distance of local airports and transition corridors;
- the amount of air traffic usually found in the area; and
- ambient noise levels within the PAO.

It is recommended that the crew create a map of the area where the PAO will be located and outline and label the PAO. Specify where the observers will be located and their area of coverage. Note obstructions located within the area of operations and identify minimum safe altitudes for either the entire area of operations or specified zones within the area of operations. Note areas within or near the PAO that should be avoided because of potential signal interference.

Entities that regularly conduct operations within a specified region (e.g., police department operations usually conduct operations within the city limits) should be aware of normal air traffic patterns and densities within that region. A survey should be conducted regularly to ensure that patterns remain relatively constant.

Finally, the development and use of checklists is recommended. These checklists should cover the information and procedures covered in these guidelines.

Operational Recommendations

At the commencement of the operation, or during the operation, the following procedures are recommended.

- Position the observers assigned to look for traffic so that they have the most unobstructed view of the sky possible, taking into account the position of the sun, glare from reflections off buildings or other objects, and signs or other large obstructions.
- Check all communications equipment being used and ensure that communications are not impeded under high-noise conditions.
- If operating close to airports, monitor applicable local Common Traffic Advisory Frequency (CTAF), departure, approach, and tower frequencies.
- If the operation is expected to last more than one hour, there should be a plan to provide a rest break for the observers. Observers should be on task for no more than one hour at a time, with a break of at least 10 minutes before resuming observation.
- If the visual observer is being used for avoidance of difficult-to-see obstacles, the operation should not be conducted during dusk, dawn, night, or limited visibility atmospheric conditions unless it is assured that the area of obstacles can be avoided.

It is possible that there will be times when two or more UAS operations will be flown within the same area simultaneously. It is important that all operations are coordinated to prevent collisions between any of the unmanned aircraft. It is recommended that there be at least one visual observer for each operation, in addition to any other visual observer requirements.

Observer Requirement Recommendations

Observers should have the following physical qualifications:

- Distance visual acuity of 20/20 or better, with or without corrective lenses.
- Normal color vision.
- Normal hearing acuity.
- No drug usage that may compromise the individual's physical or visual performance or compromise judgment. Avoid certain medications known to cause drowsiness, decreased color vision, blurred vision, and other problems.
- Observers should be counseled regarding alcohol consumption. Alcohol usage has been shown to cause visual complications of decreased vision, double vision, chronic lacrimation, pupillary dysfunction, reduced dark adaptation, nystagmus (an involuntary, rapid movement of the eyeball), and to increase central processing time, thus interfering with accurate tracking and saccadic (rapid involuntary small movements of both eyes simultaneously) eye movements. Title 14 part 91.17 states that no person may act or attempt to act as a crewmember of a civil aircraft within eight hours after consumption of any alcoholic beverage. Although this CFR section does not apply to visual observers, the provisions are strongly recommended as a pre-work limitation for these individuals.
- If the visual observers are used for a night operation, a 30-minute time period is required before they are considered fully adapted to the dark. Prolonged exposure to bright lights before the adaptation period can extend that time, as well as can the use of tobacco products. Under these conditions, a 45-minute adaptation period is recommended.

Training Recommendations

- Visual observers should be aware of cardinal directions when standing within an area of operations (i.e., they should know which direction is north, south, etc.).
- Visual observers should be trained to maintain a scanning pattern so that complete scanning of an area is accomplished.
- There should be a common set of terms for all crewmembers (i.e., observers and pilots) regarding landmarks. For example, "that building is the Founder's Building," "that is the Bay Street Bridge," "that is the Channel 5 transmission tower." There should also be a common set of terms for all crewmembers for aircraft types and operations.
- Visual observers should be aware of the location of airports and flight corridors relative to their position.

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APPENDIX A

Visual Observer Requirements From FAA Publication N8900.227, "Unmanned Aircraft Systems (UAS) Operational Approval."

14. Operational Requirements for UAS. Unless operating in an active Restricted or Warning Area designated for aviation use, or approved Prohibited Areas, UAS operations must adhere to the following requirements.

a. Observer Requirement. Visual flight rules (VFR) UAS operations may be authorized utilizing either ground-based or airborne VOs onboard a dedicated chase aircraft. A VO must be positioned to assist the PIC, to exercise the see-and-avoid responsibilities required by §§ 91.111, 91.113, and 91.115 by scanning the area around the aircraft for potentially conflicting traffic and assisting the PIC with navigational awareness.

(1) VOs:

(a) Must assist the PIC in not allowing the aircraft to operate beyond the visual line-of-sight limit, and

(b) Must be able to see the aircraft and the surrounding airspace sufficiently to assist the PIC with:

- Determining the UA's proximity to all aviation activities and other hazards (e.g., terrain, weather, structures), and
- Exercising effective control of the UA, and
- Complying with §§ 91.111, 91.113, and 91.115, and
- Preventing the UA from creating a collision hazard, and

(c) Must inform the PIC before losing sufficient visual contact with the UA or previously sighted collision hazard. This distance is predicated on the observer's normal vision. Corrective lenses, spectacles, and contact lenses are permitted.

(2) Because of field of view and distortion issues with aids to vision such as binoculars, field glasses, night vision devices, or telephoto lenses, these are allowed only for augmentation of the observer's visual capability; they cannot be used as the primary means of visual contact. When using other aids to vision, VOs must use caution to ensure the aircraft remains within normal visual line-of-sight of the observer. These aids to vision are not to be confused with corrective lenses or contact lenses, which do not alter the field of view or distort vision.

(3) The responsibility of ensuring the safety of flight and adequate visual range coverage to avoid any potential collisions remains with the PIC. The PIC for each UAS operation must identify a location from which the observer will perform his/her duties. This location will be selected to afford the best available view of the entire area within which the operation is to be conducted.

(4) Daisy-chaining of observers to increase operational distance is not normally approved; however, a proponent may provide a safety case for daisy-chaining in accordance with paragraph 16 by demonstrating an acceptable level of risk to the NAS.

(5) Observer(s) must be in place 30 minutes prior to night operations to ensure dark adaptation. Refer to subparagraph 13.i.(2)(b) for night operations information.

APPENDIX B

Visual Observer requirements From the Small Unmanned Aircraft System (sUAS) Notice of Proposed Rule-Making

- Restricted from participating in more than one aircraft operation simultaneously
- Would need to be certificated for operations under this proposed rule except for model aircraft
- Would need to be in "close proximity" to the pilot
- Should be able to communicate directly, exchange non-verbal signals, and share the same relative visual references
- The FAA would be concerned with distances more than 6-10 feet between the pilot and visual observer
- Medical standards and operational limitations in this proposed rule ensure that the pilot and visual observer are capable of scanning the airspace of intended operations. Aids to vision, such as binoculars, must be used with care to ensure that the total overall viewing of the airspace isn't inadvertently limited.
- Operations above 400 feet AGL would require one visual observer. Operations conducted beyond 1500 feet horizontally from the pilot require one visual observer. Operations above 400 AGL and beyond 1500 feet horizontally would require two visual observers
- Operations, sometimes referred to as "daisy-chain," "relay," or "leap-frogging," would not be authorized under this proposed rule
- Applicants for a Visual Observer Certificate would be required to pass a practical test with either a certified sUAS pilot or instructor
- The visual observer would be required to always know where the sUAS is and to discern the attitude and trajectory in relation to conflicting traffic, weather, or obstacles. Because of the level of vigilance that would be required in scanning the surrounding airspace, a visual observer would be prohibited from supporting more than one operation at a time
- An FAA second-class medical certificate is required for commercial operations.
- Maximum distance of aircraft from pilot-in-command
- Operations conducted under this subpart must fly no farther laterally from the pilot-in-command and/or visual observer whichever is less for each Group identified in §107.13: (1) Group A or B: 1500 feet (2) Group C, D, or E: ½ statue mile
- **§107.77 Visual observation.** Not withstanding §107.53(c), the pilot-in-command must be able to see or ensure that a visual observer is able to see the aircraft throughout the entire flight well enough to:
  - ✓ Know its location,
  - ✓ Determine its attitude and direction to exercise effective control,
  - ✓ Observe the airspace for other air traffic or hazards, and
  - ✓ Determine its altitude.
- The pilot-in-command and visual observer must:
  - ✓ Scan the airspace where sUAS operations are being conducted for any potential collision hazard.
  - ✓ Be in close proximity to each other while they are performing duties.
  - ✓ Maintain awareness of the position of the sUAS through direct visual observation. Binoculars may be used to augment the visual observer duties, but may not be used as the primary means of visual contact or as a substitute for unaided visual observation.
  - ✓ Maintain effective direct two-way communications with each other at all times. A backup communications system is required for operations where the PIC is in an enclosure and cannot directly see at least one visual observer.
- A visual observer is required in any of the following conditions:

APPENDIX B
(Continued)
Visual Observer requirements from the Small Unmanned Aircraft System (sUAS) Notice of Proposed Rule-Making

- ✓ When the pilot-in-command is in a "heads-down" or any situation that precludes the ability to perform visual observer duties.
- ✓ When the pilot-in-command is within an enclosure, at least two visual observers are required.
- ✓ Operations conducted above 400 feet AGL must have at least one dedicated visual observer, and
- ✓ Operations conducted beyond 1500 feet from the pilot-in-command must have at least one dedicated visual observer.
- ✓ When the pilot-in-command determines that a visual observer is a necessary flight crewmember to maintain the safety of the operation.
- ✓ Any Group C, D, or E aircraft operations.
- ✓ Operations conducted within Class B airspace.

APPENDIX C

Visual Observer Requirements From the Certificate of Authorization (COA) Template

Certificate of Authorization

a. Visual observers must be used at all times except in Class A airspace, active Restricted Areas, and Warning areas designated for aviation activities.

(1) The observers may either be ground-based or in a chase plane.

(2) If the chase aircraft is operating more than 100 feet above/below and/or more than ½ NM laterally of the unmanned aircraft, the chase aircraft PIC will advise the controlling ATC facility.

b. The PIC is responsible to ensure the visual observers are:

(1) Able to see the aircraft and the surrounding airspace throughout the entire flight, and

(2) Able to determine the UA's altitude, flight path, and proximity to all aviation activities and other hazards (e.g., terrain, weather, structures) sufficiently to exercise effective control of the UA to

(a) Comply with CFR 91.111, 91.113 and 91.115, and

(b) Prevent the UA from creating a collision hazard.

2. Observers must be able to communicate clearly to the pilot any instructions required to remain clear of conflicting traffic, using standard phraseology as listed in the aeronautical information manual when practical.

3. Pilots and observers must not perform crew duties for more than one unmanned aircraft at a time.

4. A PIC may rotate duties as necessary to fulfill operational requirements; a PIC must be designated at all times.

5. Pilots flying chase aircraft must not concurrently perform observer or UA pilot duties.

6. Pilot and observers must not assume concurrent duties as both pilot and observer.

7. The required number of ground observers will be in place during flight operations.

8. The use of multiple successive observers (daisy chaining) is prohibited unless otherwise authorized as a special provision.

§91.119 Minimum safe altitudes: General.

Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

(a) *Anywhere.* An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.

(b) *Over congested areas.* Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.

(c) *Over other than congested areas.* An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In those cases, the aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure.

(d) *Helicopters, powered parachutes, and weight-shift-control aircraft.* If the operation is conducted without hazard to persons or property on the surface—

(1) A helicopter may be operated at less than the minimums prescribed in paragraph (b) or (c) of this section, provided each person operating the helicopter complies with any routes or altitudes specifically prescribed for helicopters by the FAA; and

(2) A powered parachute or weight-shift-control aircraft may be operated at less than the minimums prescribed in paragraph (c) of this section.